Bose-Einstein Condensation and Kinetic Energy in Liquid ^{4}He Films

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We present neutron scattering measurements of Bose-Einstein condensation in thin films of liquid ^{4}He adsorbed on a carbon-black substrate. From the data, we detemine the single particle kinetic energy, K_4, and the condensate fraction, n_0, in these two dimensional ^{4}He films (2D) as a function of fillings.

Bose-Einstein Condensation (BEC) is of great current interest and has been demonstrated to exist in three dimensional Bose systems (3D)[1, 2]. In ^{4}He, the existence of BEC is thought to be related to the existence of superfluidity. In 3D, there is phase coherence in the condensate over macroscopic length scales which supports superflow across the whole fluid. In 2D, there can also be BEC but the coherence has a power law decay over length scales of several atomic separations only. Therefore, there is no long-range phase coherence of the BEC or long range order in 2D. However, Kosterlitz and Thouless (K-T) [3] argued that localized BEC supports a topological order and proposed a 2D superfluid phase transition. Nelson and Kosterlitz [4] showed using linear response theory that there is in fact a drop in the superfluid density at the K-T transition when T_c is approached from below.

In this context, our primary goal is to measure any observable condensate fraction, n_0, in 2D at low temperatures. The most effective method to measure the condensate is by neutron scattering at high momentum transfer. The measured quantity is directly related to the longitudinal momentum distribution $J(Q, y)$, where Q and y denote respectively the momentum and energy* transferred by the neutron to the struck atom. If present, the fraction of atoms with zero momentum transfer, n_0, contributes an unbroadened peak to $J(Q, y)$ and can be directly extracted from the data. In addition, the single particle kinetic energy K_4 can be inferred from the width α_2 of $J(Q, y)$.

The measurements were carried out on the MARI time-of-flight spectrometer at the CCLRC ISIS Facility, Rutherford Appleton Laboratory, UK. In Fig. 1, we show the measured $J(Q, y)$ for different ^{4}He fillings and temperatures. Given the relatively low intensity and statistical quality of the data, only one parameter can be reasonably determined in model fits to the data. For this reason, we investigate the normal ^{4}He first where n_0 =0. We then set all fitting parameters, except α_2, to their bulk values [6]. Once α_2 is determined from the data at T =2.5 K, we use it as input to the low T data to determine the condensate fraction, n_0. We note that in bulk ^{4}He, α_2 is essentially the same at low and high temperatures [6].

Our results for K_4 and n_0 as a function of fillings are summarized in the table below. The K_4 values decrease towards their bulk value of $\simeq$ 16 K as the system becomes less 2D. These K_4 values agree qualitatively with those measured by Pearce et al. [5] in thick ^{4}He layers adsorbed on MgO crystals. At T =1.3 K, there is essentially no condensate ($n_0 \simeq 0$).

Number of layers	1	2	4.6
K_4 (K) (T =2.5 K)	25.08±5.10	23.08±2.73	20.90±1.81
n_0 (%) (T =1.3 K)	1.8±1.7	0.0±2.2	0.0±4.7

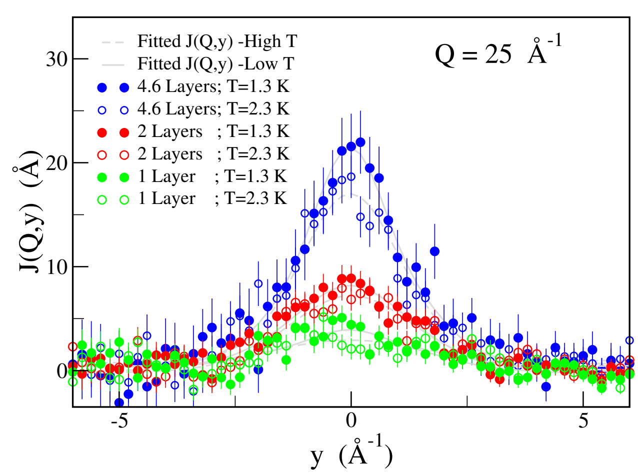

FIG. 1: Observed $J(Q, y)$ for 3 different ^{4}He filings at T =1.3 K and T =2.5 K. An increase in intensity in $J(Q, y)$ is seen as liquid ^{4}He is added and for a given filling, $J(Q, y)$ is sharper at low T than at high T, indicating the presence of a condensate.

However, recently Boninsegni and coworkers [7] simulated the One Body Density Matrix (OBDM) for 2D ^{4}He and found that at T=0.6 K, there is an effective n_0 of nearly 20 % that is not present at T =1.0 K. While the OBDM is in principle decaying in 2D, the decay at T =0.6 K is so slow that the difference between the decaying OBDM and a genuinely 'flat' OBDM tail as seen in 3D is hardly distinguishable. This exciting finding makes the measurement of n_0 in liquid ^{4}He films worth pursuing. Another measurement on MARI of BEC in this system at a lower temperature (∼0.5 K) is under preparation.

* $y \propto (E - E_r)$ where E is the real energy transfer and E_r the recoil energy.

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